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MELBOURNE, VICTORIA

Aircraft Systems Technical Memorandum 137

PROGRAMMABLE COCKPIT - HEAD-UP DISPLAY AND OUTSIDE VIEW

by

Andrew G. Page

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SUMMARY

The 'Programmable Cockpit' is a low-cost facility utilising personal computers linked together to represent the fundamental displays of a fixed-wing aircraft. The cockpit instruments can be displayed either in the conventional manner or in a 'glass-cockpit' type format. Aircraft controls include a sidestick and throttle.

It was designed so that instrument layouts and display formats could be reconfigured rapidly and tested in a reasonable aircraft representation, with the pilot under representative workload conditions. The Programmable Cockpit is to be used to study and develop the pilot-vehicle interface for future aircraft systems.

This document gives a brief overview of the complete Programmable Cockpit, including the Flight Dynamic Model, Inter-Computer Communications, Head-Down Display, Control Display Unit, and Moving Map Display. The Head-Up Display and Outside View are explained in detail. Planned development is also discussed.

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POSTAL ADDRESS: **Director, Aeronautical Research Laboratory, P.O. Box 4331, Melbourne, Victoria, 3001, Australia**

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1. INTRODUCTION

Cockpit layout and instrument format are paramount factors in deciding how well the pilot can perform. Whether the mission is military or civil, the amount and manner in which information is displayed to the flight crew is critical in realising the mission success.

A 'Programmable Cockpit - Stage 1 (PC-1)' has been developed by Flight Management Group, Aircraft Systems Division, ARL, as a low-cost facility to study various cockpit formats and methods of displaying information to the pilot. The Programmable Cockpit was so-named due to its inherent ability to re-configure the cockpit, test out a new instrument design, or vary a display format in a relatively short time.

The PC-1 consists of a mathematical aircraft model driving four display screens; Head-Down Display, Control Display Unit, Head-Up Display and Outside View, and Navigator's Moving Map Display.

This document gives a brief overview of the Programmable Cockpit. The Head-Up Display and Outside View are explained in detail. Planned development (Stage 2) is also discussed.

2. PROGRAMMABLE COCKPIT OVERVIEW

The PC-1 can be divided into hardware and software sections as follows :
(refer to reference 1 for a more detailed overview)

2.1 Hardware

The Programmable Cockpit consists of the following hardware items :

- 2 x Amiga 2500 computer
- Amiga 500 computer
- 2 x Commodore 1084 monitor with touchscreen
- NEC Multisync monitor
- IBM PS/2 monitor
- Analogue-to-digital convertor
- Throttle
- Sidestick
- Pilot seat
- Frame-work for monitors and controls

Note that the A2500 computer's each contain a 68020 and an 80286 microprocessor, and the A500 computer contains a single 68000 microprocessor. The hardware layout is shown in Figure 1.

2.2 Software

The Programmable Cockpit contains six software components :

2.2.1 Flight Dynamic Model (FDM)

The FDM is a full six degree-of-freedom aircraft model and a simple engine model. The aircraft control inputs (throttle and sidestick) are fed into the FDM via an analogue-to-digital convertor. The FDM determines the aircraft's response and updates the communications link with all the parameters used by other software sections of the Programmable Cockpit. The FDM is written in Microsoft Pascal and runs on one of the 80286 processors. Refer to reference 2 for more detail.

2.2.2 Inter-Computer Communications and Data Flow (ICC)

The ICC collects all necessary data from the FDM as it becomes available. These data are sent via parallel and serial lines to all the other microprocessors where it can be accessed as required by the various programs. The ICC is written in Modula-2 and is a background task. Refer to reference 3 for more detail.

2.2.3 Head-Down Display (HDD)

The HDD contains the basic flying instruments (altitude, indicated airspeed, vertical airspeed, compass, turn coordinator, Automatic Direction Finder, Instrument Landing System). Currently two versions exist:

Typical	-	conventional instrument panel with individual dials for each piece of information; and
Advanced	-	single CRT-type display with all information integrated onto one 'instrument'.

The HDD is written in C, runs on a 80286 processor, and is displayed on the PS/2 high-resolution monitor. Refer to reference 4 for more detail.

2.2.4 Head-Up Display and Outside View (HUD)

The HUD contains flight information(artifical horizon, altitude, airspeed, pitch angle, roll angle, heading, Mach number, g-number, and angle of attack) superimposed on the Outside View. The HUD information is not shown when the 'Typical' mode is selected. The Outside View is a night scene (current database is around the Port Phillip Bay area) concentrating mainly on airport lighting (Moorabbin, Essendon, and Melbourne). The HUD is written in Modula-2, runs on a 68020 processor, and is displayed on the NEC Multisync high-resolution monitor. The HUD and Outside View are explained in detail later in this document.

2.2.5 Navigator's Moving Map Display (MMD)

The MMD is a digital moving map showing the aircraft position over a coastline-only map. Navigation waypoints can also be displayed on the map. A 'paper map' option is available which shows more detail but is of a fixed scale, whereas the digital map has various scales. The MMD is off when the 'Typical' mode is selected. The MMD is written in Modula-2, runs on the 68000 processor (A500), and is displayed on the 1084 monitor with touchscreen. Refer to reference 5 for more detail.

2.2.6 Control Display Unit (CDU)

The CDU contains some basic engine instruments (Compressor rpm, Exhaust Gas Temperature, Engine Pressure Ratio), landing gear select, Typical/Advanced mode select, preset aircraft conditions, and a navigation system control panel which currently resembles a panel used with a real navigation system (TACTERM) developed by Flight Management

Group, Aircraft Systems Division, ARL. The touchscreen is used to enable push-button use of the systems. The CDU is written in Modula-2, runs on a 68020 processor, and is displayed on a 1084 monitor with touchscreen.

3. HEAD-UP DISPLAY

3.1 Introduction

The Head-Up method of displaying information to the pilot involves projecting flight information directly between the pilots line-of-sight and the outside world. This allows the pilot to concentrate on the out-of-cockpit situation without the need to divert his attention to cockpit instruments for flight information.

3.2 Programmable Cockpit HUD Format

The HUD currently implemented in the Programmable Cockpit is a simplified version of the F/A-18 HUD. See Figure 2. The following information is displayed :

- Airspeed, in knots, is displayed as a numeric value in the lower left box.
- Altitude, in feet, is displayed as a numeric value in the lower right box. Thousands of feet are displayed in a larger font to ensure easy readability.
- Heading and pitch angles are displayed as numeric values (top center and center right boxes respectively) and on scrolling scales. The scales also give an indication of the angular rate of change.
- The aircraft Angle-of-Attack, Mach number, and g-number are displayed as numeric values.
- A straight line to represent the horizon spans the screen.
- At the center of the HUD is a reference symbol which represents the aircraft. This symbol rotates to indicate the horizon, so that the pilot knows where the horizon is when the horizon line is not visible (very high or low pitch angles).

3.3 Graphics Programming of HUD

The graphics programming for the HUD is relatively simple, as most of the HUD is static or merely numeric displays. The moving sections of the HUD include; horizon line, aircraft symbol, and scrolling heading and pitch scales.

Using a paint program, the static section of the HUD and scrolling scales were constructed as a picture (See Figure 3) in low and high-resolution versions. Upon program initialisation the HUD-picture is drawn into a bitmap. When each fresh screen is drawn the static section of the HUD is copied from the bitmap into the current screen. Sections of the heading and pitch scales are copied from the bitmap to the screen. The numeric values are converted from integer or real values into text characters and drawn onto the screen.

The horizon line and aircraft symbol are both drawn using screen coordinates obtained from arrays indexed to roll and pitch angles. These arrays are initialised on program start-up. Modification to the array data or its indexing for angles out of the array index limits may be necessary. The limits are -50° to $+50^{\circ}$ for pitch and -90° to $+90^{\circ}$ for roll.

4. OUTSIDE VIEW

4.1 Introduction

The Outside View used for the programmable cockpit is a night scene with variable visibility (user defined, default=10km). It was considered that a night scene could be generated with reasonable realism with the available computer power. A realistic day scene would have required much more processing. See Figure 4.

4.2 Programming Methodology

Instead of using the computationally intensive matrix method of performing the transformation of ground referenced data to terminal screen coordinates and then clipping the out-of-field-of-view data, it was decided to try to reduce computation by determining the visible terrain data before doing any ground-to-screen transformations.

To do this, the screen coordinates defining the visible ground area are transformed from the screen to ground coordinates (see section 4.4) to obtain the ground coordinates (relative to the current aircraft position) of the polygon defining the visible field-of-view boundary. A box is fitted around this polygon to give an approximate field-of-view that is easy to check for terrain data..

To reduce the amount of terrain data needed to be checked, a 1km square grid system was introduced. When the terrain data base file is constructed (using a separate program, see section 4.5) the data for each grid square are made separately and are indexed to that grid, so that it is very quick to check if any terrain data are within a particular grid square. Once all the grid squares in the visible field of view have been identified, the terrain data are translated from reference ground coordinates to current aircraft position ground coordinates and transformed from ground to screen coordinates (see section 4.3). The screen coordinates are finally checked to be within the screen boundaries.

4.3 Ground-to-Screen Transformation

The ground coordinate (3-D terrain data) transformation to the terminal screen (2-D) is carried out by projecting the data point, P, along a projection line that meets the center of projection (i.e. the pilot's eyes). See Figure 5.

From reference 6 (p. 240) :

$$x_p = x(d/(z+d))$$

$$y_p = y(d/(z+d))$$

where 'd' is the perpendicular distance from the center of projection to the projection plane.

The center of projection (pilot's eyes) lies on the aircraft's heading radial. Therefore the terrain data must be transformed from North-East coordinates (P_N,P_E,P_A) to parallel and perpendicular to the heading radial (P_{para},P_{perp}).
Refer to Figure 6.

$$P_{perp} = P_N.\sin(\text{heading}) - P_E.\cos(\text{heading})$$

$$P_{para} = P_N.\cos(\text{heading}) + P_E.\sin(\text{heading})$$

The point, P, is then projected onto the plane z=0, and the point coordinates in (x,y,z) are determined as follows (See Figures 7 & 8) :

$$P_z = P_{para}\ .\cos(\text{pitch}) - d - P_A\ .\sin(\text{pitch})$$

Note : P_z must be positive for P to be visible.

Transform the point coordinates onto the projection plane (x,y,0) :

$$\text{alpha} = \tan^{-1}(P_{perp}/a)$$

$$\text{where } a = P_{para}\ .\ \sin(\text{pitch}) + P_A.\cos(\text{pitch})$$

$$\text{gamma} = \text{pi} / 2 - \text{alpha} + \text{roll}$$

$$P_x = R\ .\ \cos(\text{gamma})\ .\ b$$

$$P_y = -R\ .\ \sin(\text{gamma})\ .\ b$$

$$\text{where } R^2 = a^2 + P_{perp}{}^2$$

$$\text{and } b = d/(P_z+d)$$

Therefore the screen coordinates are:

$$X_{sc} = SW/2 - P_x$$

$$Y_{sc} = SH/2 - P_y$$

where SW = Screen-Width

and SH = Screen-Height

4.4 Screen-to-Ground Transformation

Working backwards from screen coordinates to ground coordinates using the equations derived in section 4.3 :

First, using the X equations :

$$X_{sc} = SW/2 - P_x$$

$$= SW/2 - R.\cos(gamma).b$$

$$= SW/2 - (-a.\sin(roll) + P_{perp}.\cos(roll)).(d/(P_z+d))$$

Therefore :

$$(X_{sc} - SW/2)(P_z+d) = d(P_{perp}.\cos(roll) - a.\sin(roll))$$

Substitute for P_z, P_{perp} to get this equation in terms of P_N and P_E and equate coefficients. This gives :

$$c_1.P_N + c_2.P_E + c_3 = 0$$

where :

$$c_1 = (X_{sc} - SW/2).\cos(heading).\cos(pitch)$$
$$- d.(\sin(heading).\cos(roll) - \cos(heading).\sin(roll).\sin(pitch))$$

$$c_2 = (X_{sc} - SW/2).\sin(heading).\cos(pitch)$$
$$+ d.(\cos(heading).\cos(roll) + \sin(heading).\sin(roll).\sin(pitch))$$

$$c_3 = -(X_{sc} - SW/2).Altitude.\sin(pitch) + d.Altitude.\cos(pitch).\sin(roll)$$

Similarly, for the Y equations :

$$Ysc = SH/2 - P_y$$

$$= SH/2 + R.\sin(gamma).b$$

$$= SH/2 + (a.\cos(roll) + P_{perp}.\sin(roll)).(d/(P_z+d))$$

Therefore :

$$(Y_{sc} - SH/2)(P_z+d) = d(P_{perp}.\sin(roll) + a.\cos(roll))$$

Substitute for P_z, P_{perp} to get this equation in terms of P_N and P_E and equate coefficients. This gives :

$$c_4.P_N + c_5.P_E + c_6 = 0$$

where :

$$c_4 = (Y_{sc} - SH/2).\cos(heading).\cos(pitch)$$
$$- d.(\sin(heading).\sin(roll) + \cos(heading).\sin(pitch).\cos(roll))$$

$$c_5 = (Y_{sc} - SH/2).\sin(heading).\cos(pitch)$$
$$+ d.(\cos(heading).\sin(roll) - \sin(heading).\sin(pitch).\cos(roll))$$

$$c_6 = -(Y_{sc} - SH/2).Altitude.\sin(pitch) - d.Altitude. \cos(roll).\cos(pitch)$$

Solving the two equations simultaneously for P_N and P_E gives :

$$P_E = (c_6/c_4 - c_3/c_1) / (c_2/c_1 - c_5/c_4)$$
$$P_N = -c_6/c_4 - c_5/c_4.P_E$$

4.5 Graphics Programming of Outside View

The Outside View consists solely of points of light. These light points are drawn on the screen using the *move* and *draw* graphics routines and the appropriate colour setting routine. Two methods have been incorporated to compliment perspective and the visibility limit. First, the colour of every light point is faded out in 1 to 4 steps, depending on the colour of the particular light point. Second, the number of pixels used to represent an individual light point varies from 1 to 16, proportional to the distance from the aircraft to the particular light point.

4.6 Terrain Data

The current terrain database describes an area around Port Phillip Bay, Victoria, with the main emphasis on airport lighting. Moorabbin, Essendon, and Melbourne are the major airports and were constructed first. As well as all the standard lighting (taxiway centerline, runway edge, runway threshold/end) at all three airports, Melbourne has Category I precision approach lighting, touchdown zone lighting, and T-VASIS (Visual Approach Slope Indicator System). Essendon has simplified Category I precision approach lighting. Figure 4 shows Melbourne airport Rwy 27.

The terrain data base is created using a separate Modula-2 program called makeTerrainData. Terrain data can be specified as single points of light (GroundLight) or as strings of light (LightString).

4.6.1 GroundLights

GroundLights(GL) are specified by the following parameters :

- North(N) and East(E) coordinates from the reference point
- Altitude(A) above sea level
- Color1, Color2, DirSplit
  DirSplit can be used to create uni-directional lights or lights that change color depending on the aircraft position. The color change occurs at either the North GL coordinate or the East GL coordinate.

DirSplit = 0	No direction color split i.e constant color GL (color = Color1)
DirSplit = 1	Direction color split = North if Nposition >= N then color = Color1 if Nposition < N then color = Color2
DirSplit = 2	Direction color split = East if Eposition >= E then color = Color1 if Eposition < E then color = Color2

- MaxShade
  Maximum color shade to be used for the GL. This can be used to limit the brightness of the GL relative to others.
- MaxRange
  Maximum visible range of GL. The user defined visibility limit overrides this.
- MaxSize
  Maximum dot size used to draw the groundlight. Light points are drawn using varying numbers of pixels depending on the range to that point.
  MaxSize allows the size of the GL to remain relatively smaller than other GLs.

A GroundLight is mapped to the screen using the Ground-to-Screen transformation of section 4.3 .

4.6.2 LightStrings

Lightstrings (LS) are defined by specifying the two endpoints of the string and the number of light points in the string. The following parameters specify a LightString :

- N_0, E_0, A_0 North, East, Altitude for one end of string
- N_n, E_n, A_n North, East, Altitude for the other end of string
- n Number of light points in the string
- Color1, Color2, DirSplit, MaxShade, MaxRange, MaxSize
  These parameters are as described for GroundLights, but apply to all the light points in the string.

Note that the subscripted altitudes (A_0 and A_n) are relative to the aircraft and not the ground (i.e Aircraft Altitude - Data Point Altitude).

To map a LS to the screen, both ends of the LS are transformed from the ground to screen using Ground-to-Screen (section 4.3). The lights between the endpoints are mapped to the screen using angular ratios as described below (refer to Figure 9) :

$$r_0^2 = N_0^2 + E_0^2 + A_0^2$$

$$r_n^2 = N_n^2 + E_n^2 + A_n^2$$

$$dN = N / (n-1) \quad \text{where} \quad N = N_n - N_0$$

$$dE = E / (n-1) \quad \text{where} \quad E = E_n - E_0$$

$$dA = A / (n-1) \quad \text{where} \quad A = A_n - A_0$$

$$dR = R / (n-1) \quad \text{where} \quad R^2 = N^2 + E^2 + A^2$$

Using the cosine rule gives :

$$\text{beta}_n = \cos^{-1}((R^2 - r_0^2 - r_n^2) / (-2 r_0 r_n))$$

For the i^{th} light point :

$$N_i = N_0 + i.dN$$

$$E_i = E_0 + i.dE$$

$$A_i = A_0 + i.dA$$

$$r_i^2 = N_i^2 + E_i^2 + A_i^2$$

and : $R_i = i \cdot dR$

Once again using the cosine rule gives :

$$beta_i = \cos^{-1}((R_i^2 - r_0^2 - r_i^2) / (-2 r_0 r_i))$$

Therefore, using the angular ratios :

$$Xsc_i = Xsc_0 + beta_i/beta_n \cdot Xsc$$

$$\text{where} \quad Xsc = Xsc_n - Xsc_0$$

$$Ysc_i = Ysc_0 + beta_i/beta_n \cdot Ysc$$

$$\text{where} \quad Ysc = Ysc_n - Ysc_0$$

5. PERFORMANCE

The Programmable Cockpit HUD running without any Outside View achieves a screen update rate of 9-10 Hz. When the Outside View is incorporated and the scene is reasonably detailed (as in Figure 4) the update rate decreases to approximately 2-3 Hz. This low update rate makes flying the aircraft quite difficult, especially with a high-performance aircraft. Even with the deliberately chosen 'sluggish' aircraft model, the graphics update rate is not quite rapid enough to allow the pilot to fly visually, however it does give the pilot an indication of aircraft position and whether or not the aircraft is on the desired flight path.

6. CONCLUSION

The Programmable Cockpit (Stage 1) was demonstrated for the ARL 50th Anniversary Open Week. As a concept demonstrator the PC-1 was very sucessful. Its major shortcoming is the slow update rate of the dynamic graphics displays (Head-Down and Head-Up Displays).

The next step in development (Stage 2) is the acquistion of more computer power, particularly graphics power. It is envisaged that a workstation will become the hub of the next version with some of the currently used computers as satellites doing the less intensive computation and graphics displays.

Future development of the HUD will include varying the information content, studying different display methods and symbology, and experimenting with more complicated formats. The Outside View will include more terrain data and realism effects. Depending on the update rate achieved, a daytime scene would also be attempted. The prime objective will be to obtain more rapid screen update rates, in the order of 20 Hz minimum.

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David Craven	-	Navigator's Moving Map Display, Programmable Cockpit Inter-Computer Communications and Data Flow, and Amiga graphics programming specialist.
Mario Selvestrel	-	Head-Down Display and hardware (framework, pilot seat etc.).
Brian Neil	-	Control Display Unit.
Peter Futschik	-	Throttle and Sidestick interface.

FIGURE 1 : Hardware LAYOUT

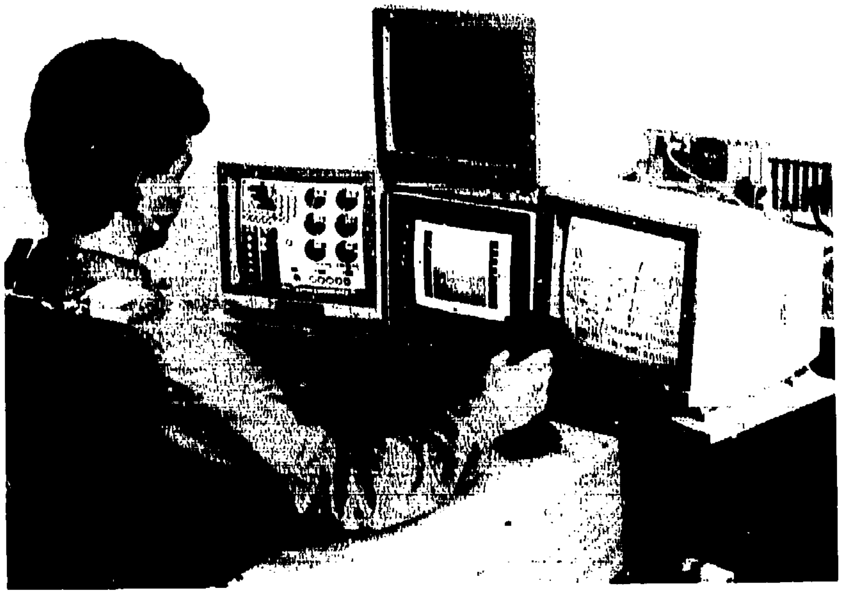


FIGURE 2 : HUD Format

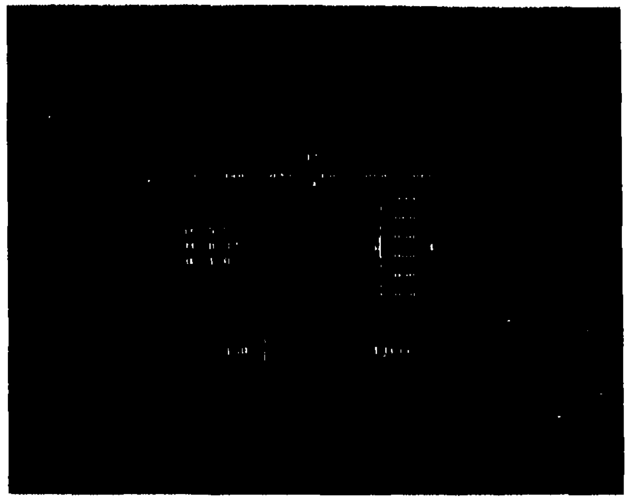


FIGURE 3 : Static HUD

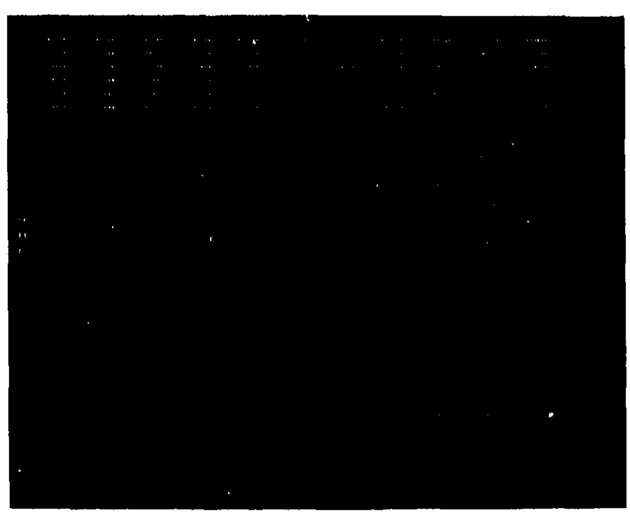


FIGURE 4 : Melbourne Rwy 27

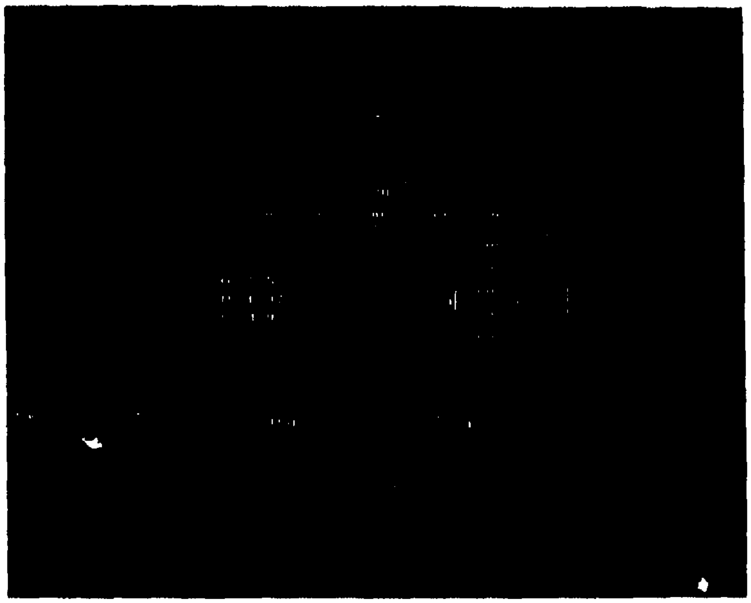


FIGURE 5 : Perspective Projection

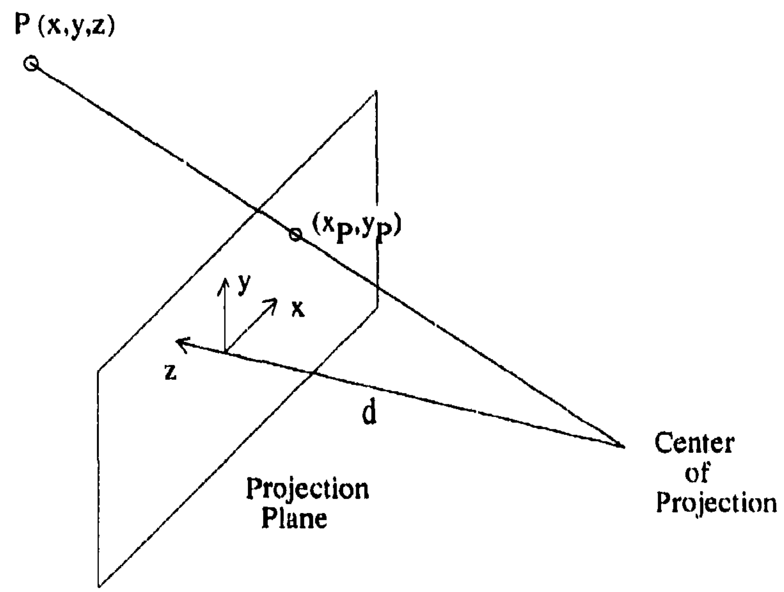


FIGURE 6 : Coordinate Systems Relative to Aircraft

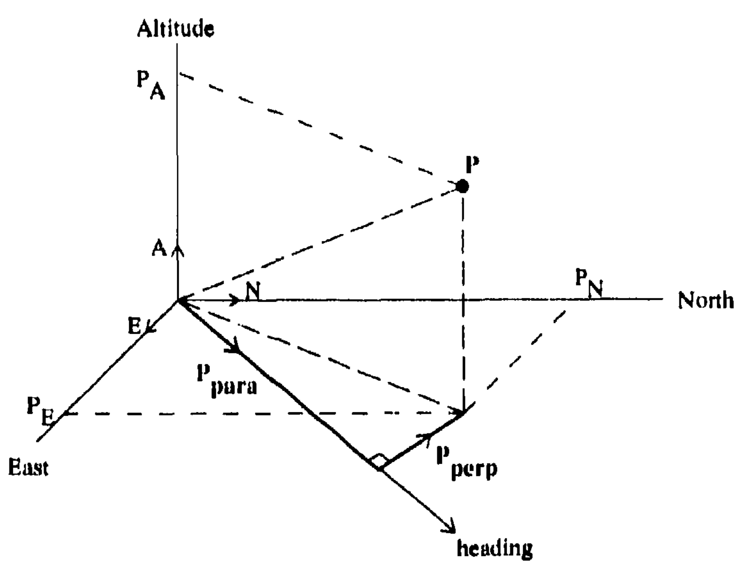


FIGURE 7 : Aircraft Projection Plane

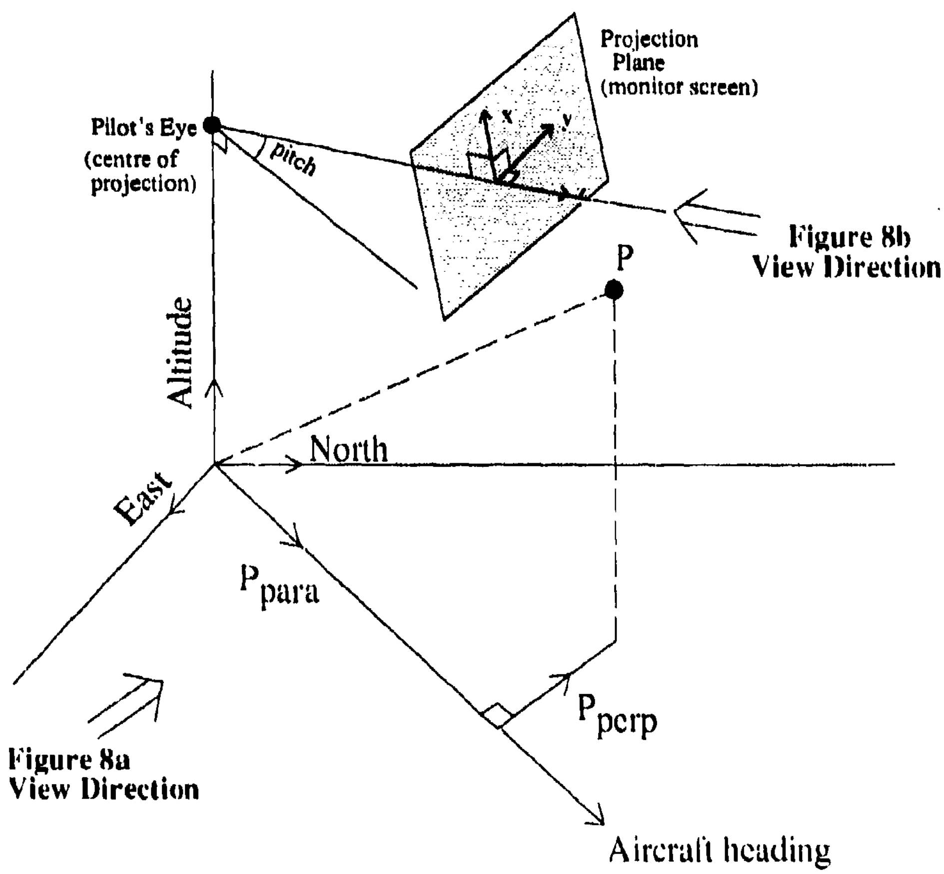
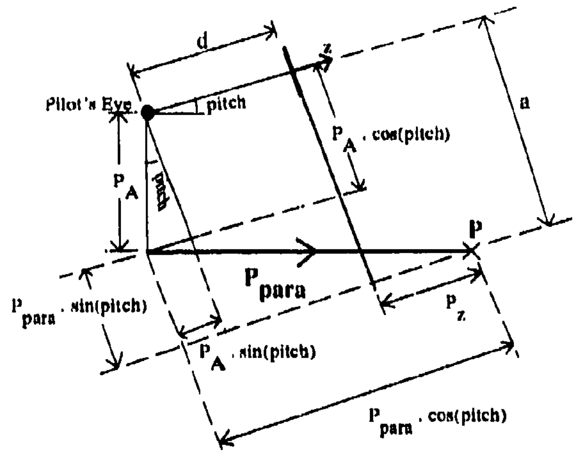
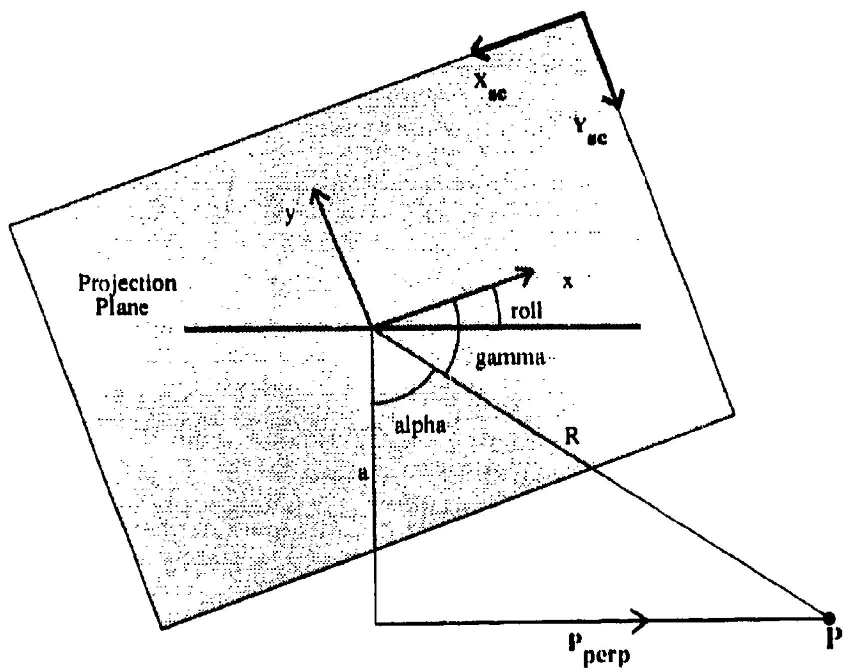


FIGURE 8 : Ground-to-Screen Transformation

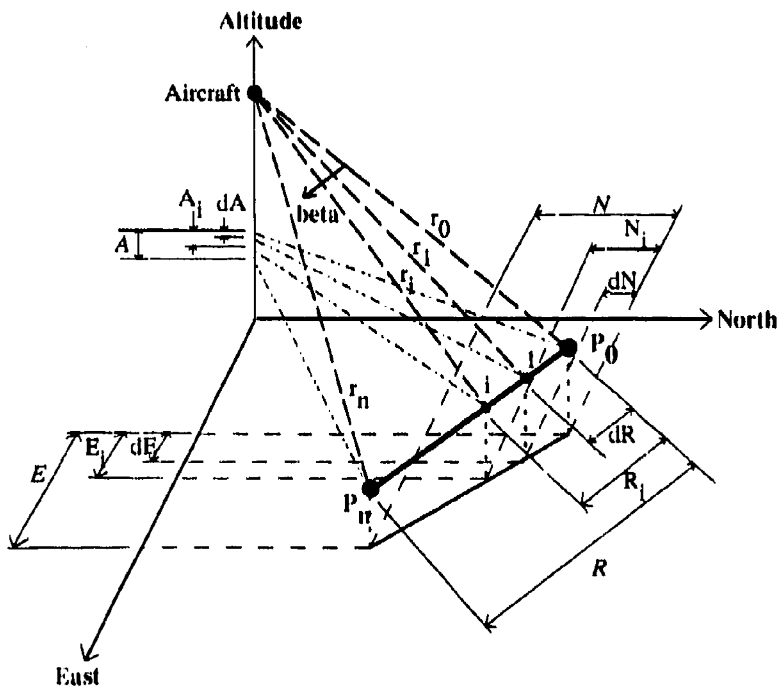


(a) View Parallel to Projection Plane



(b) View Perpendicular to Projection Plane

FIGURE 9 : Light-Strings



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14. DESCRIPTORS
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16. ABSTRACT
The 'Programmable Cockpit' is a low-cost facility utilising personal computers linked together to represent the fundamental displays of a fixed-wing aircraft. The cockpit instruments can be displayed either in the conventional manner or in a 'glass-cockpit' type format. Aircraft controls include a sidestick and throttle.

It was designed so that instrument layouts and display formats could be reconfigured rapidly and tested in a reasonable aircraft representation, with the pilot under representative workload conditions. The Programmable Cockpit is to be used to study and develop the pilot-vehicle interface for future aircraft systems.

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16. ABSTRACT (CONT).

This document gives a brief overview of the complete Programmable Cockpit, including the Flight Dynamic Model, Inter-Computer Communications, Head-Down Display, Control Display Unit, and Moving Map Display. The Head-Up Display and Outside View are explained in detail. Planned development is also discussed.

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